Fully Bio-based Phytic Acid - β-Nicotinamide Mononucleotide salt for flame retardant flexible polyurethane foam

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Abstract

The development of eco-friendly flame retardants is quite essential owing to the environmental and human health hazards of most traditional flame retardants. Herein, we reported a bio-based flame retardant, which was is synthesized from Phytic Acid (PA) and β-Nicotinamide Mononucleotide (NMN), was designed to coating on the surfaces of flexible polyurethane foam (FPUF). The PA-NMN coating significantly reduced the flammability of FPUF. Especially, compared to bare FPUF, FPUF@PA$_2$-NMN$_2$ could reach V-0 rating in the UL-94 horizontal burning foamed material test with a high limit oxygen index value of 36.6%. In addition, FPUF@PA$_2$-NMN$_2$ exhibited a remarkable reduction in the peak heat release rate, total heat release and peak smoke production rate by 81.2%, 47.6% and 37.1%, respectively. Moreover, an superior char formation performance of 44.6 wt.% residue was obtained for FPUF@PA$_2$-NMN$_2$, indicating the outstanding barrier and carbonization property of the hybrid coating. This strategy may pave a promising way for fabricating fire-safety FPUF composites with preferable comprehensive properties.

Experiment

Firstly, FPUF was cleaned three times using deionized water and anhydrous ethanol alternately before drying. The ratios of PA and NMN were adjusted to obtain the PA and NMN complex solution, which was prepared as shown in Table 1. The prepared PA-NMN complex solution was stirred at room temperature for 1 h. After the reaction was completed, the cleaned FPUF was immersed in the above solution for 30 min with repeated extrusion. Finally, the foam was taken out and dried at 60°C to prepare the flame-retardant foam.

Tab. 1 Effect of flame retardants on the combustion performance for FPUF

PA-NMN	NMN (wt.%)	PA (wt.%)
PA$_0$-NMN$_1$	1	0
PA$_{0.5}$-NMN$_1$	1	0.5
PA$_1$-NMN$_1$	1	1
PA$_{0.5}$-NMN$_0$	0	0.5
PA$_2$-NMN$_1$	1	2
PA$_2$-NMN$_2$	2	2

Results

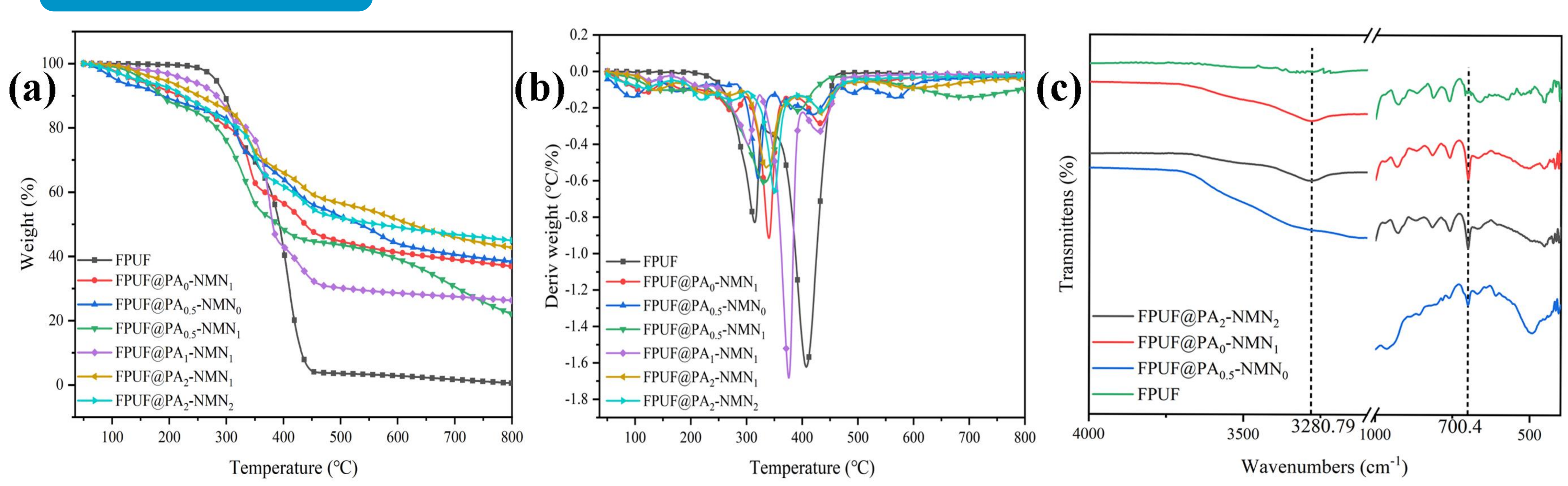

Fig.1. TGA (a) and DTG (b) curves of FPUF samples; Infrared spectra (c) of FPUF samples.

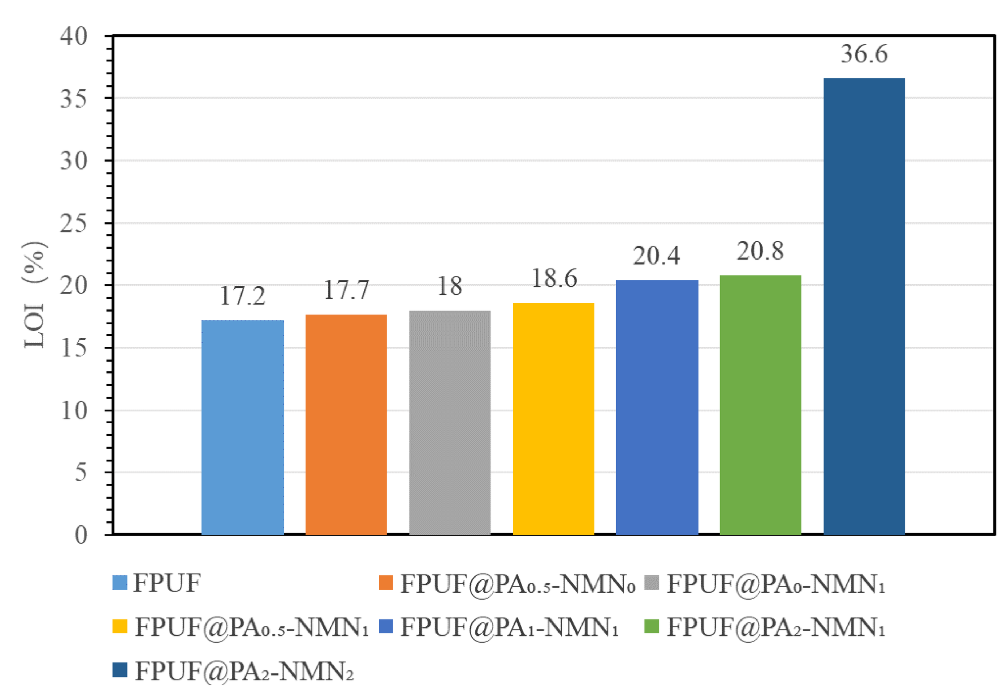

Fig.2. LOI values of FPUF samples.

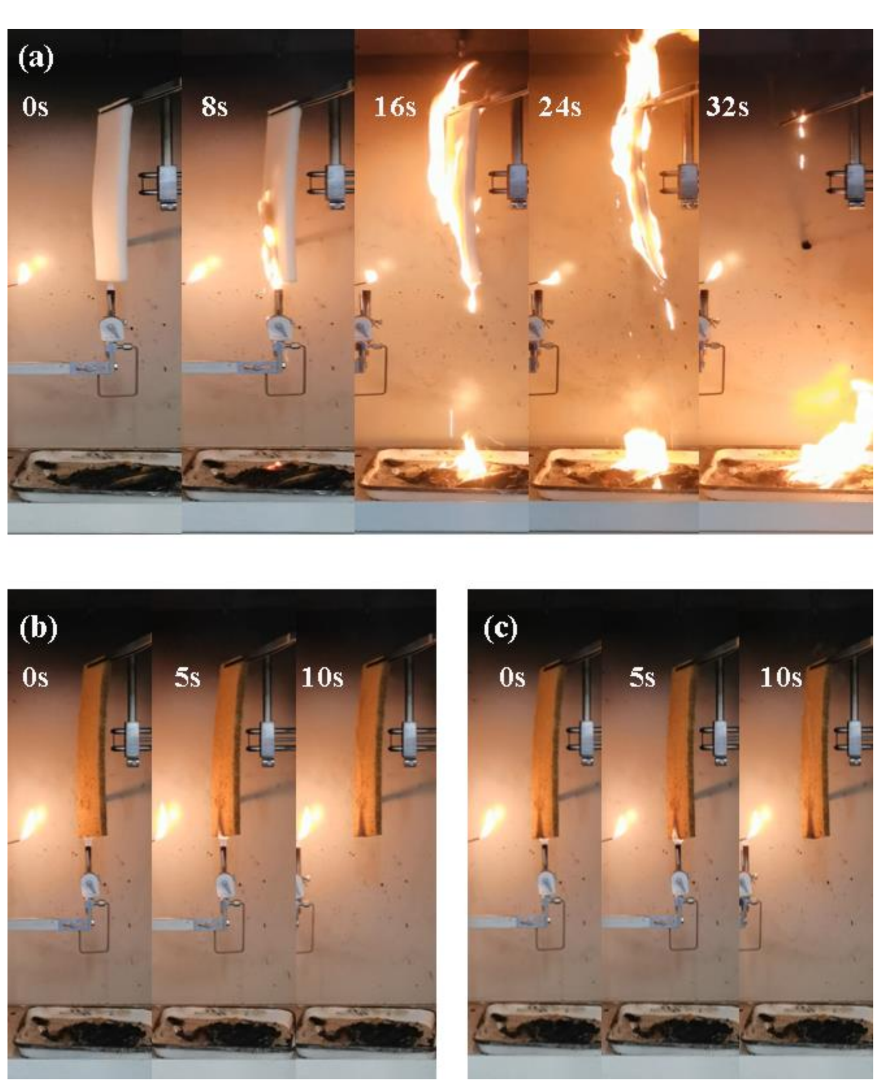

Fig.3. Vertical burning test digital photos: pure FPUF (a), FPUF@PA$_2$-NMN$_2$: first ignition(b), second ignition (c).

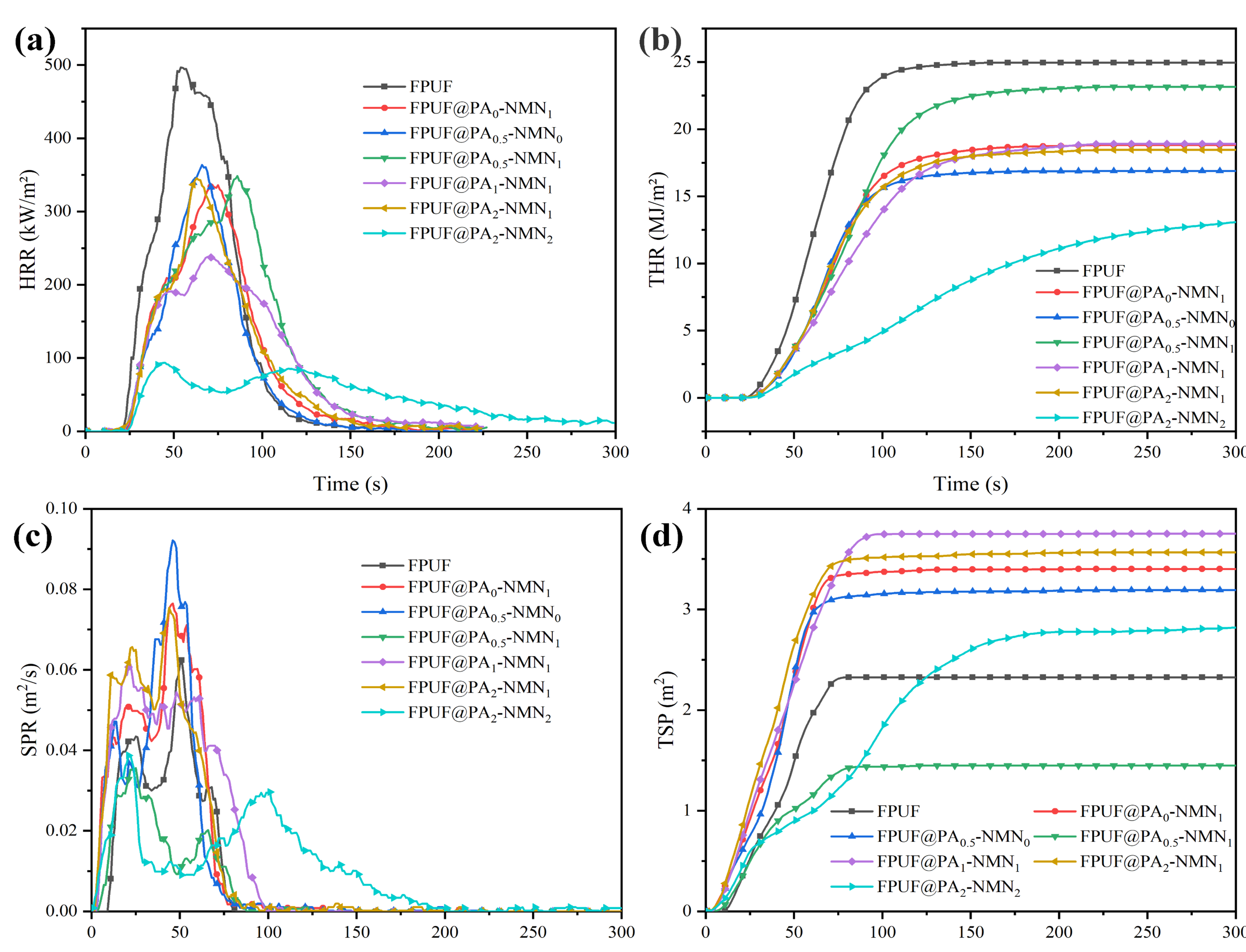

Fig.4. HRR (a), THR (b), SPR (c), and TSP(d) curves of FPUF samples.

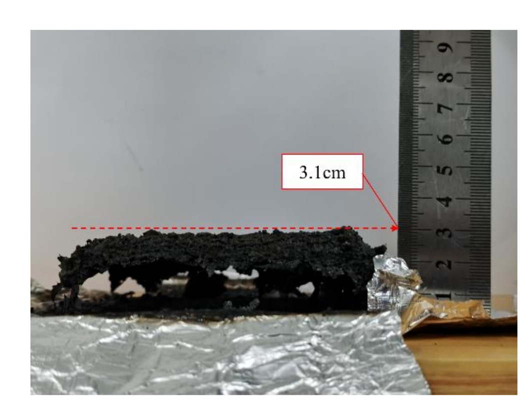

Fig.5. Digital photo of residual carbon height of FPUF@PA$_2$-NMN$_2$.

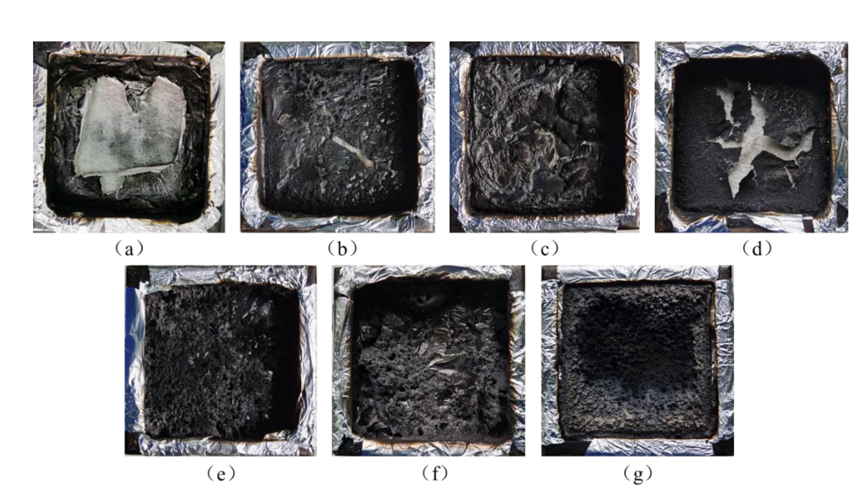

Fig.6. Digital photos of sample residues: FPUF (a), FPUF@PA$_0$-NMN$_1$ (b), FPUF@PA$_{0.5}$-NMN$_0$ (c), FPUF@PA$_{0.5}$-NMN$_1$ (d), FPUF@PA$_1$-NMN$_1$ (e), FPUF@PA$_2$-NMN$_1$ (f), FPUF@PA$_2$-NMN$_2$ (g).

Conclusion

- **The introduction of PA-NMN flame retardant coating increased the maximum thermal decomposition temperature and decreased the thermal decomposition rate of FPUF. With the PA-NMN flame retardant coating concentration higher, the residual carbon rate of the corresponding flame retardant FPUF also increased.**
- **The limiting oxygen index value of FPUF@PA$_2$-NMN$_2$ reached 36.6% and UL-94 test passed to V-0 level. Cone calorimetry tests demonstrated that the peak heat release rate, total heat release and peak smoke production rate were reduced by 81.2%, 44.8%, and 39% respectively.**
- **The residual carbon analysis indicated that the PA-NMN flame retardant coating could perform flame retardant effect on FPUF in the condensed phase. The coated foam formed an expanded carbon layer during combustion to effectively isolate the heat and oxygen transfer, as well as reduce the release of poisonous smoke, significantly improving the flame retardant and smoke suppression performance of FPUF.**